AIR COMMAND AND STAFF COLLEGE

AIR UNIVERSITY

SPEED IS LIFE: WHY MACH & MANEUVERABILITY DOMINATE IN 2030

By

Jalen A Whitener, Maj. USAF

A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

Advisors: Dr. Christopher Johnson and Dr. Heather Marshall

Maxwell Air Force Base, Alabama

June 2016

DISCLAIMER

The views expressed in this academic research paper are those of the author and do not reflect the official policy or position of the US government or the Department of Defense. In accordance with Air Force Instruction 51-303, it is not copyrighted, but is the property of the United States government.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

The next generation of fighter aircraft should possess a supersonic capability, maneuverability superior to that of US potential adversary aircraft, and incorporate new directed energy weapons technology. Enemy technology continues to evolve and challenge US stealth technology, and the current medium range air-to-air missiles in service. These capabilities and technology ensure lethality and survivability in counterair operations against these high end-threats. A scenario framework sets the stage for each of four possible future fighters to engage in high-end combat. The thesis then describes the four platforms discusses the tradeoffs in capabilities and the resultant risks and rewards of equipping the next generation fighter with various capabilities. These traits include slow/non-maneuverable vs. fast/agile aerodynamic traits and the application of kinetic weapons vs. directed energy weapons to each of the two aerodynamic possibilities. A final qualitative scoring of the platform's risks and rewards in lethality, survivability and projection (range) supports the thesis' recommendations on which aircraft best meets these requirements. The thesis concludes with recommendations for US and USAF leadership to bring the best asset to fruition and opportunities for further research.

INTRODUCTION

March 27, 1999, is a day the stealth community will not soon forget. At approximately 8:00 PM, Vega 31, an F-117 "Stink Bug" flying out of Aviano AB, Italy, was returning home after executing a tasking near Belgrade, Serbia. As he flew, feeling invisible in his low signature aircraft, warheads from a Russian-built SA-3 began to detonate all around him. Before he was able to evade further engagement, a missile from a 1960s-era surface-to-air missile system detonated close enough to fatally damage his aircraft, forcing him to eject before crossing back into friendly territory. It was the fourth night of Operation Allied Force. Stealth aircraft had seen combat in Operation Desert Storm and elsewhere, but none had been tracked well enough for missile guidance, until then.[1]

Fortunately, US combat search and rescue personnel recovered Vega 31 that same night.[2] The glaring reality, however, was that he had been taken down by the very systems the F-117 was designed to penetrate. Years later during an interview, Col. Zoltan Dani, the air defense commander responsible for the shoot down, stated that Serbian forces detected his aircraft using "electromagnetic waves."[3] Experts interpret his vague statement to refer to the long wave frequencies employed by most modern radars in service today. Systems currently being produced and sold by Russia and China possess modern versions of these radars, thus highlighting that the stealth "solution" to enemy radar tracking and weapons cueing is not necessarily enduring.[4]

PROBLEM BACKGROUND

Although the Serbs engaged the F-117 that night, the incident proved to be a very small dark spot in an otherwise bright new technology. Today, as a testament to its perceived value, development of stealth and (and subsequently counter-stealth) systems continues to progress.

Stealth weapon systems like the US F-22 and F-35, the Russian T-50, and the Chinese J-20 and J-31 constitute the fifth generation of aircraft development. As a counter to this threat, Russia is deploying and selling the S-400 surface-to-air missile system, which is regarded as the most capable system available to track US fifth-generation aircraft and low observable missiles.[5] It is worth noting that S-400 developers claim the capability to track low observable vehicles out to half their engagement range, although this is nebulous given the classification of testing data.[6] China also has its own stealth tracking radar, called the Type 517M, which has been observed on ships operated by the Peoples Liberation Army Navy (PLAN).[7]

Several factors drive these technological developments in Russia and China, including both a perceived technological disadvantage and an alleged US intrusion into their respective regions. [8] These, along with Russian and Chinese territorial aggression against nations like Georgia, Crimea, Japan, the Philippines, and others appears to be a motivating factor for significant investment in military growth and modernization for both nations. To counter perceived threats from the US, Russia and China have adopted an Anti-Access/Area Denial (A2/AD) strategy using a variety of technologies like advanced IADS and their own stealth fighters to repel US forces.[9] As part of the effort to counter this strategy, US military and civilian leadership have begun researching a sixth-generation fighter and its requisite capabilities.

Counter-stealth radar advances and adversary stealth development are not the only technologies creating problems for US fighter aircraft in the A2/AD environment. Several countries continue to progress in infrared search and tracking (IRST) systems development, which can detect low-observable aircraft at “ranges compatible with a beyond visual range missile launch.”[10] No doubt this statement is intentionally vague given the sensitivity of the new capability to its developers and customers. US allies in Sweden and Italy are considered to be the leaders in IRST development, but Chinese and Russian industries continue to improve as well.[11] Russia has employed an IRST on virtually all of its fighters for years and is no stranger to the technology and its potential. China, though less experienced, also developed its own IRST for its newest fighters.[12]

As a result of this rapid modernization, and the US's relatively stagnated development cycle, military and civilian leadership acknowledge that the US technological edge is eroding. To address this issue, former Secretary of Defense, Chuck Hagel initiated the "Third Offset Strategy" innovation project to spur thought and development in how to re-establish the US' advantage.[13] As part of this initiative, USAF Chief of Staff General Mark Welsh instituted the "Air Superiority 2030" Enterprise Capability Collaboration Team (ECCT).[14] This team published a report in early 2016 that recommended future technologies and operations concepts to ensure air superiority success over the next several decades.[15] As a result of that study, Gen Welsh directed Air Force Core Function Leads to focus efforts on several Capability Development Areas, one of which is the "Target and Engage" portion of the kill chain. [16] Notably, this capability area could equate to anything, including fighter jets or engagement concepts that break from fighter platforms altogether. The flight plan states that "Capability development efforts for [Penetrating Counter Air] (PCA) will focus on maximizing tradeoffs between range, payload, survivability, lethality, affordability, and supportability...and will allow the stand-in application of kinetic and non-kinetic effects from the air-domain."[17] Also worth noting is the team's desire to break from "thinking focused on next generation platforms" due to the undesired effect this type of thinking has on the development process.[18] As the ECCT conducted its research however, US corporations had already began submitting concepts and preliminary designs for the Navy's sixth-generation fighter in response to DoD contract solicitations already in place. Due to secrecy, these submissions contained little detail on specific capabilities and characteristics.[19]

One of the specific capability developments mentioned by the report includes "game-changing technologies" like directed energy and hypersonic weapons. Of particular interest to this project is the directed energy weapons focus—particularly high energy lasers—which will play a significant role in this thesis. Laser weapons have been in development since the 1960's.[20] Dr. Jason Ellis argues that directed energy weapons have the "potential to yield cost effective weapons that can deliver precise, scalable effects – and at long ranges – with a large magazine capacity." Since the 1960s, DOD has spent billions on experimentation with disappointing results, particularly in the early 2000s.[21] Although the technologies behind these results have been somewhat divested since that time, newer types of laser technologies that show more legitimate promise have matured significantly, in spite of reduced funding for high energy laser R&D.[22]

While Dr. Ellis considers DE development up through 2015, this project explores the possible application of the developmental weapons he identifies to fighter platforms in 2030 and beyond. In line with the Air Superiority 2030 ECCT's key concept of pairing new weapons to delivery platforms the following research offers one approach to doing so. [23]

LITERARY REVIEW

As the USAF and USN determine the direction for development of their respective services, debate is ongoing regarding the fighter characteristics that offer the highest utility. In their paper on fighter characteristics (released in 2012), Kadir Yildiz, et al., argues that fighters should possess certain characteristics to demonstrate superior capability and deter the enemy from attacking.[24] These include: low observability, speed, maneuverability, range, persistence, datalinks, self-protection, and modern weapons. They conclude that speed and maneuverability are essential to defeat incoming missiles, increase sortie production, and to effectively escort and rejoin with strike packages after engaging enemy fighters, ultimately deterring the enemy from aggression.[25] In one of the first projects to address the characteristics of a sixth-generation fighter, Maj. Brandon Abel in 2014 assesses what these aircraft should be able to do. He postulates that stealth technology, weapon advancements, and sensor developments will create a "new paradigm" in air superiority aircraft characteristics that breaks away from traditional fighter aircraft requirements in favor of subsonic, higher payload, long-range designs.[26] He concludes that a platform with strategic caliber range and a payload of 16 air-to-air missiles will provide greater utility than a shorter range, fast, and maneuverable fighter in future conflict.[27] In 2015, Dr. John Stillion of the Center for Strategic and Budgetary Assessments advocates for similar characteristics as Maj. Abel. He argues that a long range, semi-autonomous network of unmanned combat aerial vehicles with long and very long range weapons will be the most effective air superiority tool. He further argues that the demand for situational awareness, information acquisition, and information denial will negate the utility of current fast and agile fighter platforms. He acknowledges however, that this fighting unit heavily relies on data links and information sharing, and could not execute if that data link was compromised.[28]

The aforementioned research conclusions do not consider the historical trend that US adversaries have countered every radar technology evolution, at least to some degree. For the stealth example, VHF radar advances enable them to cue ultra-high frequency engagement radars to stealth platforms, and are far cheaper to produce.[29] If one applies this theory to a broader spectrum of technology, like adversary jamming versus US radars, it then follows that adversary nations will likely develop technology or adapt their tactics to enable adversary aircraft to penetrate US sensors. Should this happen, US aircraft will need speed and agility to either escape or to engage and defeat enemy aircraft. Not all research however ignores this probability.

In his article released in early 2016, Col. Mike Pietrucha highlights the previously discussed fact that some of the advantages boasted by current fifth generation stealth platforms are being eroded. He argues that because stealth aircraft could be tracked using VHF or IR sensors that are quickly being produced and proliferated by US adversaries, that the USAF should return to terrain masking, low-level fighting tactics once thought obsolete, while capitalizing on electronic attack techniques.[30]

Though Col. Pietrucha acknowledges the eroding advantage of stealth technology, there are other novel considerations missing from each of these research projects, like the development and application of new technologies to the air superiority fight. Those that consider the evolution of the adversary's technology leave emerging weapons like directed energy weapons out of the conversation. Mr. Yadiz, does use an example where a fighter shoots 'modern' weapons; however, the weapons he describes are only evolutionary improvements on current technology.[31] Also notable in Mr. Yadiz's argument is the claim that after shooting while at supersonic speeds, the aircraft would turn away at supersonic speeds (as opposed to turning at subsonic speeds, and *then* accelerating to supersonic speeds) to escape the enemy attack.[32] It is a mathematical fact that turn radius, when above Mach 1.0, increases drastically, equating to significantly reduced maneuverability when above the mach. [33] Therefore his proposed advantage in maneuverability is lost because of its desired use at speeds above Mach 1.

Col. Pietrucha also chooses not to consider directed energy weapons, but argues for revisiting low-level, terrain masking tactics.[34] This approach however, would likely only be successful in a strike capacity with standoff jamming support from a medium altitude, thus putting the jammer at risk or requiring an extended range jamming capability. The low-level approach also assumes that terrain is available to mask the radar signal the entire way to the target. Given that terrain masking will not be an option in every scenario, one must consider that new systems like the S-400 are optimized for low and very low altitude targets.[35] These yet unaddressed considerations in emerging technology as well as current trends in A2/AD technology development form the genesis of this project, which seeks to explore possible scenarios combining differing aircraft characteristics with developmental weapons technology to envision the most lethal, survivable attributes for the USAF's next air superiority fighter.

RESEARCH ARGUMENT

The following research shows that the next generation of fighter aircraft should possess a supersonic capability, maneuverability superior to that of US potential adversary aircraft, and incorporate new directed energy weapons technology. The ongoing cat and mouse game of technological development will keep the possibility of a visual engagement or threat reactions that rely on these characteristics relevant and will thus drive the need for a responsive, survivable strike and air defense platform. Additionally, technology advances in electronic attack and electronic protection continue to reduce the probability of a radar guided missile's successful engagement of its target, thus creating the need for a new class of weapons. Current technological developments suggest that aircraft will soon be traceable (and therefore targetable) regardless of their signature management technique.[36] This condition will likely require US planners to overcome the surface-to-air threat through means other than signature management techniques on fighter/strike aircraft before sending them forward to interdict enemy movements and protect US ground and maritime forces. When the advanced IADS are rendered ineffective, then US aircraft will depend on speed and agility to minimize exposure to other threats, including adversary aircraft or alternative tracking techniques. From a defensive stand-point, fighter ranges far outpace US surface-to-air missile capabilities and will likely continue to serve as the first line of defense against air threats to US bases and maritime assets in the global commons. It follows that giving up speed and maneuverability, in favor of signature management, payload, and range maximizing traits would hinder the defensive capabilities of these aircraft (i.e. its ability to intercept incoming threats at the maximum distance from the defended area), thus further limiting the Air Force's ability to achieve success through the air domain. Some argue that technology will evolve to negate the utility of speed, because friction from the high airflow increases an aircraft's heat signature (making it vulnerable to passive IR sensors) and the need for greater range and payload will trump the smaller fighter size aircraft's limitations in these areas.[37] The increasing capability of IRST technology, however, will allow it to detect aircraft at even subsonic speeds, negating part of the advantage of a subsonic airframe. Since World War II, when radar began to be used in a military capacity, US adversaries have developed defensive counters for nearly every offensive technology the US has developed at a fraction of the cost.[38] The most current example is the US fifth generation fighter and its stealth technology, which is designed to penetrate Russian and Chinese IADS. This stealth advantage is quickly being challenged by multiple technologies, including radars using Very High-Frequency (VHF) wavelengths and passive infrared sensors in multiple frequency ranges.[39] This is not to say that stealth technology or signature management techniques will not be relevant in future aircraft. To the contrary, this project assumes that stealth, heat dissipation, and other signature management techniques will inevitably be a significant part of sixth-generation aircraft design. The point of divergence from the theory of dependence on signature management technology lies in this project's position that to rely *solely* on stealth and IR signature management to ensure survivability and lethality would not be prudent; particularly to the extent that one might give up the maneuverability and speed required to penetrate and escape modern defenses and weapons systems in the name of minimizing radio frequency (RF) and IR signatures and maximizing range and payload.

The need to retain speed and maneuverability goes far beyond counter-stealth technology proliferation. Some argue that increased payload comes at the cost of maneuverability due to weight and volume of space (and therefore size of the aircraft) required. Development of directed energy weapons will significantly increase the available payload to any aircraft equipped with them thus increasing and broadening the types of effects a given platform can provide.[40] Applying this technology to fighter sized aircraft solves the payload limitations a fighter has when carrying kinetic missiles, and allows it to remain survivable in contingency situations. Though slower, less maneuverable aircraft also enjoy the benefits of directed energy weapons, they are not survivable when confronted by adversary fighters at close range. US Navy leadership is already discussing the need for these technologies, and companies like Northrop and Boeing are answering with F/A-XX sixth-generation concepts that both provide an initial concept for application of these new weapons and address the associated heat dissipation concerns that these types of weapons create.[41]

As the United States continues to pursue a multi-pronged approach to securing freedom of access and re-assuring its security partners around the globe, the Department of Defense must leverage multi-domain, joint capabilities. Combining the emerging capabilities of space and air assets using directed energy, coupled with emerging cyber capabilities to form the "family of capabilities" sought by the Air Superiority 2030 Flight Plan, has the potential to yield extremely efficient results in a manner likely unaccounted for by US adversaries. Packaging these potential capabilities in a slow, un-maneuverable aircraft that seeks to accomplish multiple missions using its advantages in range and payload capacity will likely fail to yield the desired effectiveness or cost efficiencies. Doing so ultimately risks the USAF's ability to ensure success in deterring the enemy or guaranteeing victory in conflict.[42] The alternative of retaining the ability to maneuver and rapidly penetrate, respond, strike, and escape will better enable victory for the US in any endeavor.

DISPELLING PREVIOUS CLAIMS:

How New Information Affects Previous Research on Sixth Gen Fighters

Research into the sixth-generation aircraft is limited, and as previously noted, has only been published formally over the last two years. Several military senior leaders have discussed the concept, and Gen. Welsh's ECCT is the USAF's first and only endeavor thus far to dig deeply into the subject. For this research, it is important to identify technological advancements that change the calculus for aircraft requirements and potentially negate the basis for previous arguments.

First, those who argue that sixth-generation aircraft will not need to go supersonic suggest that supersonic speeds generate a significantly higher heat signature due to engine temperatures generated by supersonic aircraft and skin friction from the high airflow.[43] GE is keenly aware of the heat signature issues caused by engine heat, and is currently developing the ACE engine, which addresses these concerns with new air flow heat dissipation technology.[44]

Additionally, many IRST producers claim to be able to track targets at even slower, subsonic speeds, effectively negating the benefits gained by creating a subsonic aircraft in the name of IR signature management.[45] These technologies could change the assumptions behind research pursuing a subsonic aircraft (that lacks the ability and power to maneuver or the acceleration to escape) due to IR signature management concerns.

Those who argue for a significantly higher payload do so to address an anticipated numerical disparity that favors the adversary and the requirement for more missiles to kill a single aircraft, resulting from a highly contested electromagnetic combat environment.[46] USAF leadership argues that the technological improvement the US's potential adversaries are making in jamming and other electronic attack avenues, will result in a reduced probability of kill for a single missile versus a single aircraft. This reality would subsequently increase the number of missiles required to kill an enemy aircraft. The probability of kill issue could be satisfied in the near term by the advent of fighter-borne laser weapons, which could negate the need for high payload conventional weapon shooters all together. To this end, DARPA continues to conduct research and development, projecting that lasers will fit on fighter size aircraft by 2020.[47]

Finally, the requirement for greater range (and thus the requisite engine efficiency) is driven largely by the geography of the southwest Pacific. US security partnerships and commitments there require the US to be able to defend allies and secure access from a “safe area” that is several hundred (or over a thousand) miles from the potential conflict area. With the aforementioned advances in A2/AD networks, the US's ability to place force-extending tankers and even to introduce maritime assets within effective ranges is quickly being challenged.[48] The lack of basing options in the region compounds the challenge, especially given that many of these bases now find themselves within reach of Chinese ballistic missiles.[49] Further, there is an added sense of urgency with the current high tensions over land disputes and China's militarization of artificial islands in the South and East China Seas.[50] Nations all around the southwest Pacific feel threatened by China's territorial ambitions and aggression, adding to the sense of urgency and the need for the US to re-assure its allies of its commitment to security in the region. These issues all add to the requirement that the next platform be able to operate from a range that allows it to accomplish the mission. The platform must also be able to operate without accepting excessive risk either to tankers, other support aircraft, or to the airfields/carriers from which it operates.

To counter the problem of conducting battle over extended ranges, the Navy continues to pursue technology that will increase the survivability of its maritime assets in the anti-access environment, allowing US assets to operate within the necessary proximities to their objective.[51] Additionally, the US keeps building partnerships in the southwest Pacific in order to secure basing options for its assets and to increase the number of targets that the enemy must neutralize to deny the area to US and allied forces. Both actions serve the purpose of reducing the required operating ranges for air superiority assets in the South China Sea area of responsibility. With regard to fuel efficiency and resulting range capability, GE's ACE engine again helps to address these concerns, boasting a 20% fuel efficiency increase, and a resulting 25% range increase.[52]

With these new technologies and institutional pursuits in mind, this examination of previous research shows a need for further discussion what capabilities and characteristics of an air superiority platform will remain the most lethal, survivable, projectable assets in future conflict. Specifically, the lack of consideration of what happens when these new platforms find themselves in a close or visual range engagement or how the application of directed energy weapons will affect the need for particular characteristics demonstrates a need for a closer look at aircraft lethality and survivability. USAF doctrine describes air superiority as a pre-requisite for joint operations in a contested environment[53] thus making it imperative that US air superiority platforms remain the most lethal and survivable platforms on the global market. To this end, the following research looks to add to the discussion the consideration of contingency scenarios involving close or visual range combat as well as and emerging technologies to illustrate the enduring need for speed and agility on future air superiority assets.

RESEARCH FRAMEWORK

This project will use a scenario planning framework to evaluate possible outcomes of the application of differing fighter characteristics and various classes of weapons on future "target and engage" platforms. This framework is well suited to illustrating the tradeoffs between the different characteristics in a combat environment. The project will first identify key factors driving the development of the next fighter and then it will compare opposing flight characteristics and weapons classes, analyzing them through a scenario continuation to determine which ones provide the greatest utility to the USAF. Next, analysis of the scenarios using the key factors will address important concerns for USAF and DoD leadership to consider during future fighter development. Once the analysis is complete, tradeoffs affecting overall utility of the platform will be qualitatively evaluated using a weighted risk-reward matrix.

Four scenarios compare and contrast the traits and the tradeoffs on two types of aircraft. The first primarily relies on stealth and other signature management techniques for survivability and possesses large weapons payload and extended range for lethality. The other relies on speed and maneuverability, coupled with stealth technology for survivability, but possesses a smaller payload and shorter range. To generate the four separate scenarios, two types of weapons will then be applied to the two platforms analyzed, the first being current or near future conventional type missiles and air-to-ground weapons, and the second being directed energy weapons.

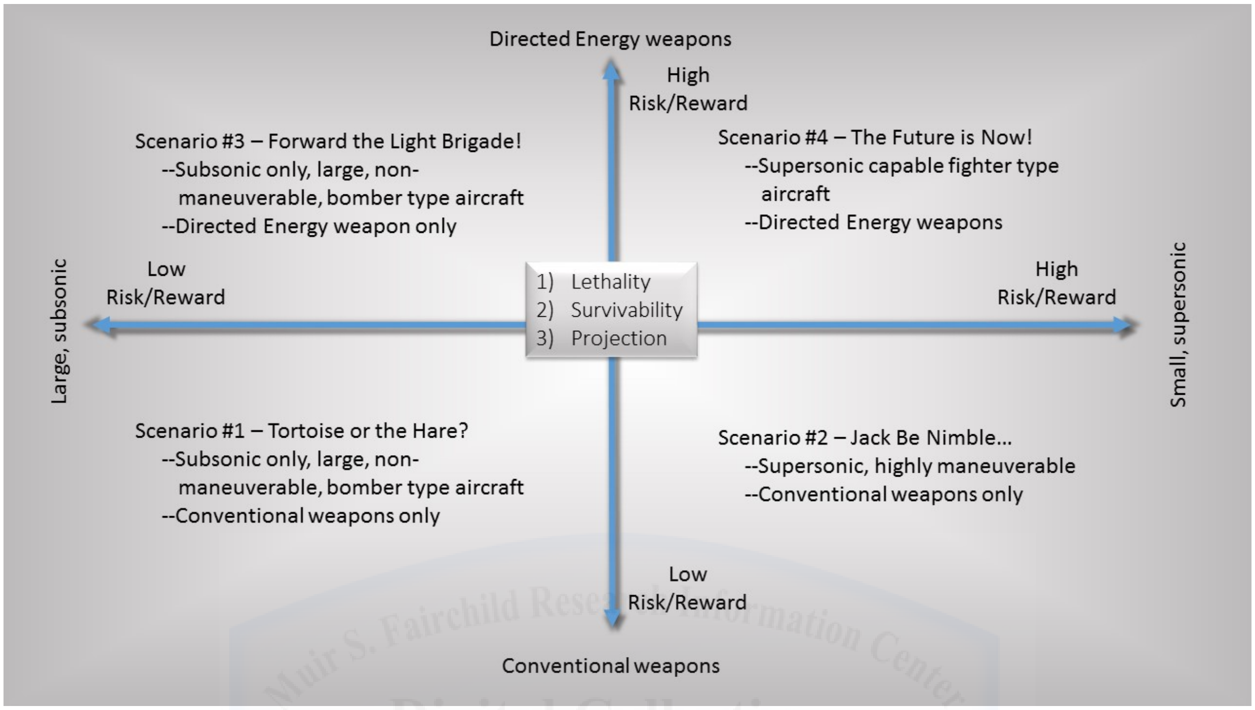

Figure 1 Scenario matrix

Following the model for scenario thinking described by Diana Scearce, and Katherine Fulton, each of the driving factors will be evaluated for risks and rewards using three "guiding principles:" the long view, outside-in thinking, and multiple perspectives. These three lenses help to thoroughly vet each scenario in order to glean as much relevant data as possible.[54]

Comparisons will be scored on a basis of risk and potential reward in applying the various characteristics for each scenario's aircraft. Points will be awarded, in order of precedence, for: 1) Lethality (+/-3 points) 2) Survivability (+/-2 points) 3) Projection (+/-1 point). A "0" will be awarded if the factor is considered neither a strength nor a weakness for a given platform. Lethality encompasses the fighter's ability to destroy as many targets, both air and ground, as possible and in the most efficient way with regard to time in the threat area. Survivability encompasses the aircraft's signature management capabilities in all portions of the frequency spectrum (e.g. visual, IR, VHF, UHF, etc.) and its ability to defeat or deny enemy attacks and to escape or avoid enemy weapons engagement zones. Projection refers to the aircraft's ability to take its capabilities to the enemy, unhindered by distance. An aircraft with a greater range capability will score better in the comparison than an aircraft with lower range. Certainly these are not the only relevant factors; however, for the purpose of this research, they are the baseline assumptions and serve to define the overall scope of this project.

Having completed the scenario analysis, the scores will be tallied and analyzed for actions to take to make the most favorable scenario reality. Further recommendations will be made as to what supporting technologies should be matured for the recommendations to remain valid. Acknowledgements to counter arguments that may invalidate this research will follow, and the project will then close with the overall conclusion.

SCENARIO NARRATIVE

Consider a day when China has established military bases on the Senkaku and Spratley islands. Russian S-400 and S-500 air defense systems actively scan the region from these same bases, and squadrons of J-20 and J-31, Su-35 and J-11B aircraft operate a continuous CAP and alert rotation from airstrips and carriers deployed there. Additionally, US ISR assets confirm the placement of GPS jamming equipment, ASAT missile sites and numerous special mission aircraft equipped with advanced electronic attack and electronic protection assets throughout the region. The Chinese Navy (PLAN) and Naval Air Force (PLANAF) regularly patrol the East and South China Sea, after the Chinese government declared its sovereign territorial waters to extend out to the nine-dashed line surrounding the South China Sea. Maritime patrols, employing the type 517M stealth tracking radar, monitor and track US aircraft movements and execute alert launches against USAF F-22 patrols, but aborting the intercept well outside weapons employment ranges, demonstrating the knowledge and ability to locate and track stealth aircraft Maritime patrols of the sea routes are at an all-time high, and both Chinese aircraft carriers, operational with J-31 naval variants, continue to patrol while conducting drills with their carrier battle groups in the region. Merchant ships have been issued travel warnings for the area, and civilian traffic has all but stopped on the routes. Meanwhile, the Chinese PLAN boards, inspects, and detains international merchant ships on once commonly used trade routes if they do not possess the appropriate permit and authorization to transit the area. These permits however, are only available at a high cost to ships origination from nations

Figure 2. Chinese territorial Claims: 9 dashed line (Reprinted from the Wall Street Journal)

holding a security agreement with the Chinese government. Meanwhile, China declares that any engagement of a Chinese asset or violation of Chinese sovereignty, identified as the nine-dash line, constitutes an existential threat to the Chinese people, which will garner the strongest possible response.

After multiple attempted rounds of resolution in the UN Security Council, ASEAN summits, and the reinvigorated South East Asia Treaty Organization,[55] the SEATO nations finally resolve to guarantee access to the regional commons in the South and East China seas, condemning the aggressive actions of the Chinese. To preserve the security and economic viability of the allied nations, the United States and its coalition re-establish freedom of movement operations throughout the Southeast Asian region, thus setting the stage for significant conflict. As forces mass and hostilities commence, talk of military engagement becomes reality. Navy destroyers armed with rail-guns and laser weapons, SEAD drone swarms, and sub-surface drones with cruise missiles and anti-sea mine technology all begin to move toward the disputed international commons to sweep the South China Sea for military assets that would deny them access.

Figure 3. Conceptual image - SAT based laser. (Reprinted from thestack.com)

As US and Coalition assets move into the region, crossing the nine-dashed line, the first slew of medium range ballistic missiles (MRBMs) are detected from orbit, and counter fire is commenced by satellite based, counter inter-continental ballistic missile (ICBM) lasers as well as

Gen III THAAD counter ASAT missiles and rail guns from US bases around the theater. Space-based assets begin to locate and target the S-400 and S-500 sites both on the islands and the mainland of China with radar-blinding energy pulses, while swarms of drones saturate their sensors with objects and electronic attack measures that overload the processors on the IADS. Space and Cyber domain assets also begin to pinpoint Chinese carrier battle groups and enable anti-jamming protocols while employing SAT based lasers[56] to disable the type 517M as well. Employing a combination of hypersonic cruise missiles, directed energy weapons, precision-guided bombs, and assets from across the DoD, the Coalition begins to engage hostile threats in pursuit of air superiority. As US Naval, Cyber and Space assets begin to punch the proverbial hole in China's surface and subsurface A2/AD wall, USAF fighters simultaneously penetrate China's air defense identification zone (ADIZ) (defined by the nine-dashed line), relying on space and cyber assets to engage and blind stealth tracking sensors, and anticipating the launch of enemy fighters seeking to counter the air attack.

SCENARIO ASSUMPTIONS

Underscoring the following scenarios are several assumptions about technological development and aircraft capabilities. They are as follows: directed energy weapons are mature and operational on fighter-sized aircraft; the US has solidified its position as a non-participant in any anti-space weapons treaties, all diplomatic and political courses of action for peaceful resolution have been exhausted; aerodynamic design for tailless fighter aircraft has progressed to enable a highly maneuverable fighter with no vertical surfaces, in pursuit of low observability traits; adversary acquisition and tracking radars or passive sensors (e.g. VHF radar and IRST) can acquire and track stealth platforms with sufficient fidelity to cue weapons; cyber capabilities are mature enough to employ offensive tactics to achieve tangible effects (e.g. datalink termination/interruption, processor overload, power termination, etc.) in the initial stages of combat operations.

Some circumstantial assumptions are also made, which drive the analysis on survivability and range and the associated risks and rewards. These include a numerical disparity that far exceeds any conflict in which the US participated since the Korea and Vietnam conflicts.[57] In Desert Storm, the adversary had a smaller Air Force, and flew significantly fewer sorties, resulting in a reduced number of visual merges.[58] The assumption here is that China has a significantly larger relative air force strength than previous US adversaries. The larger Air Force coupled with more technologically advanced capabilities will result in a higher probability of close range engagements than historical numbers show.[59] Power projection then is then enable for the smaller fighter sized airframes by other capabilities beyond the scope of this project. Basing options are assumed to be available due to force protection measures enabled by technologies that reduce the risk to US assets at bases previously assumed to be targeted by MRBMs, anti-ship missiles and other threats to US basing options.

SCENARIO ANALYSIS

The following are four scenarios that represent plausible alternatives to the events following the previous narrative. They are not intended to (nor could they) be all-inclusive, but they can offer discussion on why speed and maneuverability remain necessary for air superiority aircraft. The scenarios center around aircraft variants labeled as "F-X1, F-X2, F-X3, and F-X4," which delineate between characteristics unique to each scenario. What is the most lethal, survivable, and credible asset the US can produce to support the aforementioned scenario? What type of weapons will most effectively accomplish the task of gaining and maintaining air superiority, thus enabling the movement of maritime and ground assets as they counter surface and sub-surface threats? Through a risk-reward analysis using the lenses of the long view, outside-in thinking, and multiples perspectives, this project provides recommendations to each of those questions.

<u>Scenario #1: TORTOISE OR THE HARE?</u>

Figure 4. F-X1 - represented by the LRS-B (B-21) (Reprinted from www.us.af.mil)

In this scenario, the USAF possesses the F-X1, which is an aircraft similar in shape and design to the B-21. USAF leadership elected to equip this airframe with more technologically mature kinetic missiles. A larger fuselage enables it to carry upwards of 20 air-to-air missiles and sufficient fuel to reach nearly around the globe without refueling. The concept is largely based on Maj. Abel's and Dr. Stillion's design recommendations from their respective publications.[60] Its primary feature is its capability to maneuver through radar signals virtually unseen when outside a particular range from enemy tracking radars. This low observable technology is optimized for both UHF and VHF band radars through its tailless, flying wing fuselage design and radar absorbent skin coatings. As part of its full spectrum low observable design, its engines are some of the lowest heat signature engines ever designed to counter medium and long wave infrared detection technology. Additionally, its skin coating possesses new heat dissipation technology that further reduces the heat signature put off by the aircraft. This scenario closely resembles the characteristics and recommendations of Mr. Stillion of the CSBA.[61]

This aircraft constitutes the leading edge of the force described in the original narrative as it penetrates the A2/AD network. As stated, the objective is to demonstrate the US's commitment to freedom of movement operations and to eliminate any threats to US or Coalition assets in international waters and airspace.

Analysis

This aircraft possesses a strong capability against an air threat that is unaware of F-X1's presence and is therefore unable to avoid its sensors or weapons. With modern sensors and fused information from integrated networks, this aircraft is highly capable of destroying enemy fighters or other aircraft using weapons with superior range and counter EA technology. As a tradeoff to its air-air payload capacity, it also has the ability to carry air-surface weapons, expanding its overall utility to the USAF. As this aircraft continues to penetrate enemy airspace and maneuver around Chinese patrolled waters, it relies on datalinks to track enemy ship locations in order to stay the necessary distance away from hostile radar coverage, thus ensuring it goes undetected.

For the long view, one might consider what types of developments enemy forces may make. For instance, what if the Chinese developed very long-range weapons that removed the first shot advantage enjoyed by F-X1? The PL-21 extended range air-air missile concept is already in development in China, although few details are available.[62] Unclassified PL-21 ranges are assessed to be approximately 55NM, just under double that of the current AIM-120 Advanced Medium Range Air to Air Missile (AMRAAM unclassified ranges of approximately 30NM).[63] Because it is assumed that the PL-21 uses a ram-jet engine, its range would extend significantly longer than those missiles using solid rocket motors like the AMRAAM.[64] With the PL-21's extended range, F-X1 would need to avoid or successfully penetrate the adversary's counter stealth technology. Additionally, the very long-range missiles mentioned by Dr. Stillion of the CSBA would need to match or exceed the capabilities of the ram-jet propelled PL-21 missile.[65]

If this missile were developed and employed in combat, a logical assumption would be that it had some sort of counter-stealth cueing capability, whether built in to the missile seeker or from a third party source. Ongoing counter-stealth technology developments make this assumption quite reasonable, and the logical progression would be to apply this technology to fighter radars and eventually to missile seekers.[66] The capability for the adversary to see and shoot first would significantly challenge the operational concept behind F-X1's subsonic, stealth dependent characteristics because the success of F-X1 depends largely on the extended ranges of its weapons to maintain an advantage in combat. If the first look, first shot, first kill capability were challenged, then the only remaining advantage for F-X1 would be its low observability traits. However, when facing radars designed to counter stealth technology, even this advantage is questionable at best, thus bringing into question the utility of F-X1 as a whole. There is more to the problem, however, than competing weapons ranges and stealth effectiveness.

Taking a step back, the outside perspective on this debate might consider the additional types of technology required to enable F-X1. For instance, Mr. Stillion portrays a networked unit of UCAV aircraft, where F-X1 is the command node for the formation and the UCAVs act as missile "mules," engaging targets designated by the pilots of F-X1. This type of network requires seamless data-linked information flow, basing, and support infrastructure for the UCAV fleet as well as a far more complex signature management maneuver strategy as these aircraft maneuver in and around adversary radar coverage.[67]

The UCAV aircraft themselves could be launched from aircraft carriers or land bases, much like the USN X-47B UCLASS; but in order to accommodate significant numbers as might be required to execute theater wide air superiority operations, an increased amount of real-estate would be required to accommodate the UCAVs in addition to that required for the other manned platforms deployed throughout the theater.[68] Although the infrastructure and other requirements are typically lower than that of a manned aircraft, basing options in the Pacific theater are scarce when compared to those around the European theater (never mind the premium for space aboard an aircraft carrier) and could strain combatant commanders' options with regard to asset allocation.

The data links themselves represent both a force multiplication opportunity and vulnerability at the same time. In terms of force multiplication, several articles regarding the F-35 thoroughly describe the command and control, intelligence, surveillance, and reconnaissance, and target cueing capabilities that could also be applied to F-X1 as force multiplying technologies.[69] As a vulnerability though, Mr. Stillion acknowledges that the data links could be open to jamming and intercept.[70] The USAF is however, keenly aware of the vulnerability of its data links, networks, and other cyber domain capabilities. Gen. Welsh addresses this in the USAF Strategic Master Plan where he calls on USAF leaders and developers to build a resilient and redundant architecture that will ultimately reduce the net vulnerability to localized electronic attack or cyber-attacks from enemy forces.[71]

To consider another perspective on F-X1's subsonic, stealth capability, one might contemplate the outcome of the scenario where enemy fighters penetrate F-X1's sensors. Assume for the moment that enemy counter-stealth technology successfully locates an F-X1 and guides an enemy fighter to its location, shielded by the clutter of multiple additional enemy aircraft. Should this happen, F-X1 would have to face an adversary who advanced to within a weapons engagement zone without being engaged by F-X1. One must now consider the problem of advancing IRST technology. Due to the rapid advance and high proliferation of IRST technology, the USAF can expect that IR tracking and weapons cueing will be a significant threat in close range engagements.[72]

To counter this threat, F-X1's signature management technology will likely include heat dissipation and IR signature management technology. Northrop Grummun is heavily focused on this concept in its design submission for the Navy's F/A-XX.[73] If F-X1 possessed this IR signature management technology, which includes heat dissipating materials and subsonic airspeed limits, then target acquisition by an enemy aircraft could be delayed long enough to allow F-X1 the opportunity to escape or to detect the aircraft just soon enough to engage it before being engaged by enemy fighters. However, once detected, an aircraft must be able to maneuver quickly enough to decoy the IR sensor and depart the sensor field of view to deny the enemy a shot.

Once the shot is denied or defeated, follow-on maneuvering then is required in one of two ways. First, and most desirably, F-X1 would turn and run thus avoiding close maneuvering. This maneuver can be successful if F-X1 breaks the enemy sensor track or is able to turn and run at a range sufficient to avoid the enemy's stern weapons engagement zone. The second, and least desirable option is to merge with the enemy fighter and maneuver to achieve an offensive weapons engagement zone, thus surviving by killing the enemy first. This requires knowledge of what sensor has found and tracked F-X1 in the first place, as well as motors that can accelerate to sufficient airspeed to avoid being over-taken by the enemy fighter. F-X1, however, is not equipped with powerful engines and is too large to allow for such maneuverability. The outcome of this engagement would likely be a losing prospect for F-X1, especially if it took place at or near visual acquisition ranges.

<u>Scenario #2 JACK BE NIMBLE…</u>

F-X2's characteristics differ significantly from that of F-X1. This aircraft retains the ability to travel at supersonic speeds and to maneuver sufficiently to be successful in a visual engagement with the adversary's most maneuverable fighter aircraft, represented by the Russian SU-35.[74] It also possesses stealth characteristics such as a tailless airframe; however, it gives up the wing shaped design and larger payload capacity in favor of a more

Figure 5. F-X2 – represented by Boeing's 6th Gen Fighter concept (Reprinted from Breakingdefense.com)

maneuverable, supersonic airframe. USAF leadership also elected to equip F-X2 with the latest kinetic air-to-air missiles in traditional fighter quantities (4-6 missiles), and hit as limited capacity for air-ground engagement.

Analysis

For this airframe, one taking the long view might consider the implications of a high efficiency motor and its application to this nimble airframe. Currently, General Electric Corporation is developing the ACE jet engine, which boasts 25 percent greater fuel efficiency, 30 percent greater range, and a significant improvement in heat dissipation capabilities.[75] GE is anticipating that the US government will award the production contract in 2016. An increase in range and loiter time—without having to trade thrust (and thus airspeed and maneuver potential)—would help alleviate the strain on US forces if basing options were limited to greater distances from the desired targets or contested airspace.

While the AIM-120 AMRAAM air-air missile has been the missile of choice for the DoD and other US allies since the 1980s, new kinematic weapons such as Lockheed Martin's "Cuda" kinematic kill missile (i.e. no warhead to detonate, weapon must impact the aircraft to kill it) are in development to help alleviate the payload limitations imposed by internal carriage only stealth aircraft designs.[76] These types of long-view developments could serve to make the smaller more maneuverable fighter more lethal and give it greater reach at the same time. These two characteristics have been competing interests in years past.[77]

Although the large increase in range and thrust is good, the question remains as to whether it will be enough to satisfy the DoD's future requirements. Such parameters can only truly be realized when circumstances surrounding a conflict are realized at the onset of hostilities, but the range increase alone from GE's ACE engine is likely not enough to provide unrefueled access for a fighter-sized aircraft to sweep, interdict, or provide escort to areas deep within China or Russia. Whether or not that type of reach is the intent of DoD leadership for the next aircraft remains to be seen.

Looking in from the outside, one might consider the implications of losing basing options near enough to the contested area to operate fighter aircraft directly in support of counter-air operations. If this were to happen, the reason the basing options were lost would play a large role in determining US leadership's actions to acquire or re-acquire those bases. If they were lost to attack, then the USAF would depend on resilience and restoration ops to re-establish the foothold needed to be successful in the conflict. If, however, they were lost due to diplomatic reasons, then alternative approaches through other nations, carrier-based operations and intensified diplomatic engagement would all be required to keep the F-X2 relevant to the fight. Although it is not the intent of the DoD leadership to create a plan that depends on the presence or success of a single platform or tactic, keeping the sixth-generation fighter in the fight would likely remain pivotal in achieving operational objectives in the most efficient manner possible.[78]

An alternative perspective to the need for F-X2 type characteristics might consider the airframe design to be extremely similar to the F-35, begging the question of why this platform qualifies as a sixth-generation platform. At first glance, there is little that is different from the F-35 that makes F-X2 a revolutionary (or even evolutionary) next-generation aircraft. Improved stealth design, with more efficient, higher thrust motors and the capacity for more, smaller weapons (that currently remain untested for reliability) are all better than current F-35 technology, but only incrementally so. In this case, cost becomes a significant factor for new fighter development. If the US is unable to realize an order of magnitude utility or capability increase, especially in the context of the current search for a Third Offset Strategy, then the question remains as to whether the typically significant cost of developing a new fighter is worth the result found in F-X2.[79]

The weakness of F-X2 lies in its lack of game-changing new technology. It represents the most risk averse option in development, with little change from the current F-35. The overall characteristics and capabilities manifest in any aircraft must demonstrate to the enemy that it is capable of penetrating its defenses, exacting unacceptable loses, and returning to fight another day in order to be an effective deterrent. For F-X2, the mere incremental increases in capability leave the question of whether the adversary can compete with these advances open to debate.

Scenario #3 "FORWARD THE LIGHT BRIGADE!"

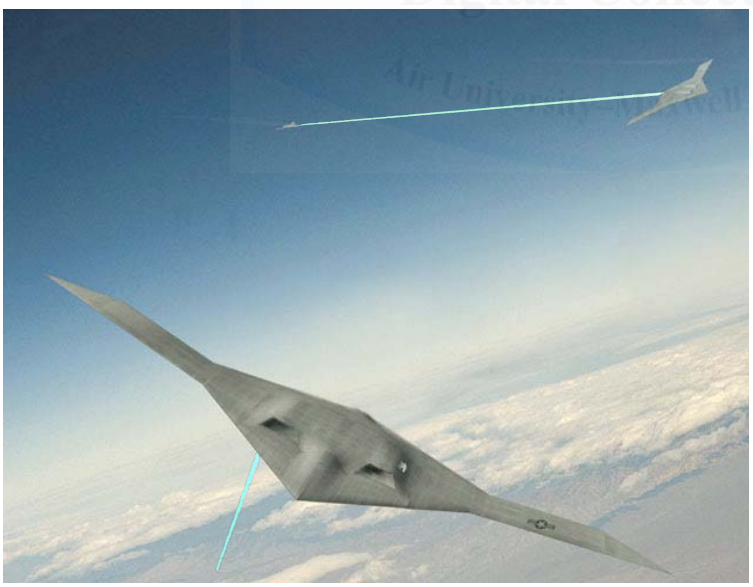

Figure 6. F-X3 – Northrop JUCAS rendering with author overlay (Adapted from http://forums.bharat-rakshak.com/)

F-X3 is the counter-part to F-X1. It has all the same aerodynamic characteristics (i.e. larger size and is subsonic only with heavy emphasis on signature management techniques) but during development USAF leadership elected to take the riskier path and equip this airframe with High Energy Laser weapons for air-to-air and air-to-ground engagement, in addition to retaining the ability to drop bombs on surface targets. This concept assumes that directed energy is mature enough to apply to air superiority aircraft, and that the effective range of these weapons is sufficient to employ at ranges similar to that of current and future air-to-air missiles. Figure 7 illustrates both proven and developmental laser effective ranges.[80]

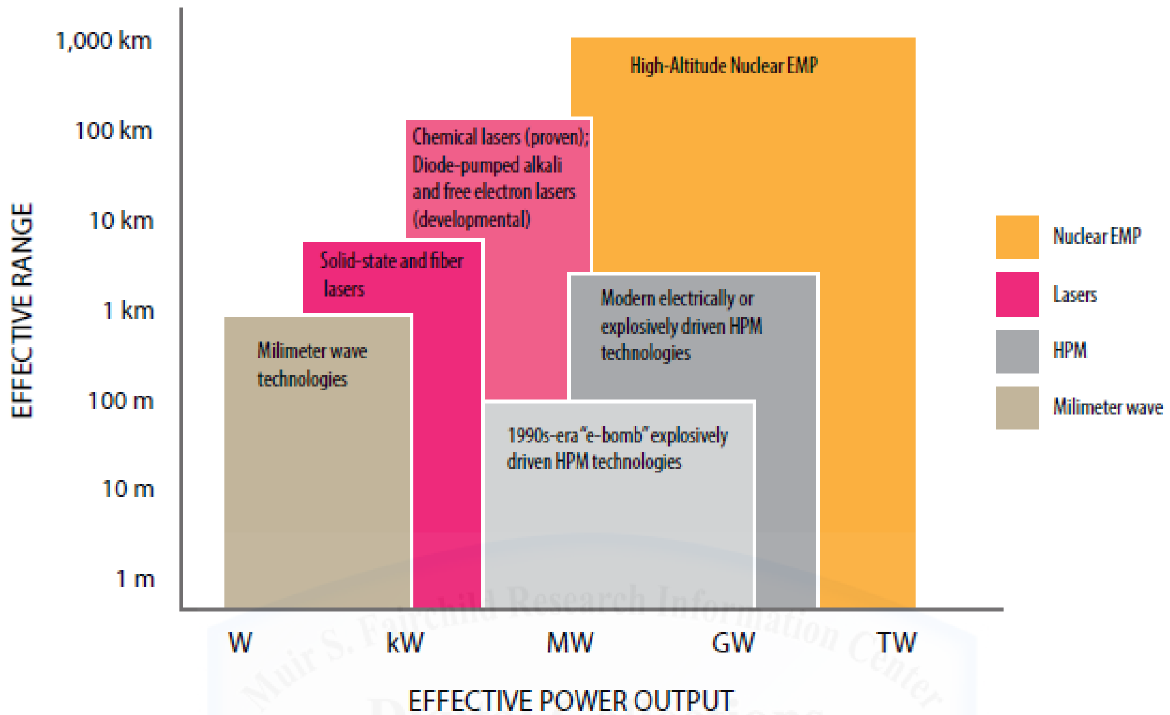

Figure 7. Effective Range of Directed Energy Weapons
(Reprinted from CNAS report: "Directed Energy Weapons")

Analysis

In this case, the long view might consider the outcome if the adversary develops a counter or defensive technology to directed energy weapons. Both China and Russia are currently pursuing development of their own directed energy weapons.[81] Although little assessment of foreign directed energy development has been accomplished, logic dictates that these nations would also look into counter directed energy weapons, given the general knowledge of US interest in directed energy weapons.

Because there are so many types of directed energy, as illustrated by Figure 7, it would be difficult for China or Russia to develop defenses in short order. If they were able to do so, then it would pose a major problem for US pilots and operational planners. This scenario gives cause for maintaining a kinetic air-to-air weapon capability such as Raytheon's Small Advanced Capabilities Missile or Lockheed's "Cuda" to retain tactical flexibility and lethality.[82] The option to carry many kinetic weapons in addition to directed energy is a strength of F-X3's design.

If the F-X3 found its lasers ineffective due to enemy counter directed energy technology, the ability to follow with kinetic weapons would enable it to remain lethal and survivable. One scenario where this fails to hold true involves the adversary's development of defensive laser capabilities such as those being pursued by the USAF and USN.[83] If the enemy fighter nullifies the effects of friendly laser weapons and effectively shields itself from kinetic missiles using its own defensive lasers, the friendly fighter no longer holds any weapons advantage. On the other hand, assuming the number of enemy fighters being engaged is less than the number of missiles available, F-X3 can remain successful against counter DE technology.

However, if those aircraft outnumber the available missiles, which is to say nothing of the known probability of kill limitations for radar-cued missiles in the expected EA saturated environment,[84] F-X3 could find itself in a scenario where short-range engagements become much more probable. As F-X1 experienced, the lack of ability to maneuver into a weapons engagement zone or to retreat at a speed sufficient to escape enemy kinetic missile ranges results in an un-survivable situation for F-X3.

One looking at this scenario from the outside-in could ask how F-X3 will attack ground targets, given its combined armament of kinetic and directed energy weapons. This problem is complex to say the least. Directed energy weapons technology for this type of engagement is currently developmental.[85] Based on concepts that apply laser weapons against other airborne and maritime soft targets, vulnerable surface targets will likely include aircraft, vehicles, ships, unhardened, above ground facilities and similar soft targets. This means that other counter-air ground targets like C2 bunkers, reinforced IADS facilities, and so forth will still likely require kinetic weapons. F-X3 would theoretically have the capability to carry such weapons, thus increasing its lethality by growing the spectrum of targets it can engage. However, requiring it to do so detracts from its overall ability to engage air targets. The trade-off then is between the number of air targets F-X3 can engage versus the number and type of surface targets it can engage.

Why this trade-off is a significant factor is a question someone approaching the problem from another perspective might ask. Is it a bad thing to have an aircraft that can shoot DE weapons, carry kinetic missiles, and still have the capacity to carry air-to-surface weapons that effectively give it the ability to hit the full spectrum of target types? At first glance, the answer would be "no;" being able to penetrate, self-escort and engage ground targets is a great concept. However, with the advent of the LRS-B (B-21), which theoretically has the capacity for all these things, one must also consider the utility of developing a new aircraft specifically to combine these capabilities, when a viable solution to this line of thinking likely already exists. Furthermore, the USAF Air Superiority 2030 Flight Plan identifies that a "family of capabilities" is the preferred direction for future development. Creating a platform that combines technology to perform escort, sweep, and attack a full spectrum of surface target breaks from this direction at its outset.

The most significant counter-point to F-X3's combined DE, kinetic air-to-air, and its ability to engage all types of air-to-surface targets goes back to a previous point about the lack of ability to survive if and when an adversary was able to reach a close or within visual range engagement. The high weapons capacity significantly increases the lethality of the platform by increasing the number and types of targets it can engage; however, its survivability depends on its ability to detect and engage 100% of the threats it faces at range, with no ability to escape or survive if only one of those threats gets through. It is therefore difficult to argue for the utility of such a platform in a high risk, highly contested environment where the likelihood of close range engagement is greater than historically experienced.[86]

Scenario #4 THE FUTURE IS NOW

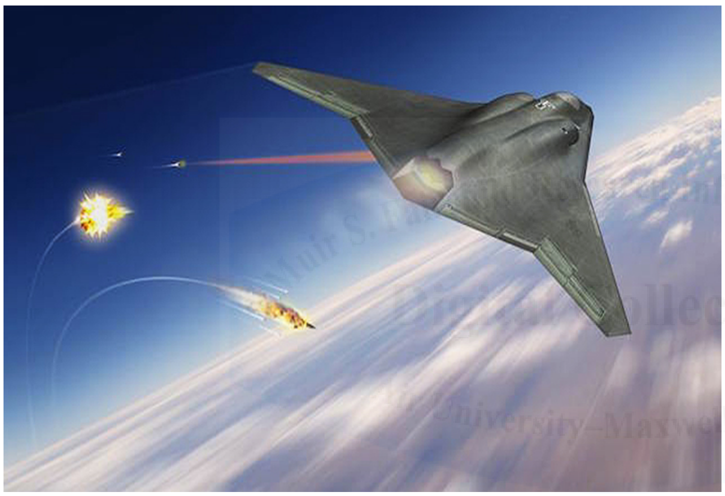

Figure 8. F-X4 - Represented by Northrop's 6th Gen fighter concept (Reprinted from breakingdefense.com)

F-X4 constitutes the primary recommendation of this project. Like F-X2, its characteristics include maneuverability that rivals any competitor aircraft Russia and China are producing. It has stealth material and design characteristics for RF signature management, as well as heat dissipation and engine cooling technology for IR signature management.[87] Unlike F-X2, however, this platform's payload is significantly increased due to the decision to equip with high energy lasers for air-to-air engagements.[88] It also retains a limited capability for conventional air-to-surface weapons in order to strike hardened or subsurface targets shielded from directed energy weapons. It represents the quintessential fighter in speed, maneuverability, range, and payload.

Analysis

With a long view on future development, one might consider potential adversaries' progress on their own directed energy weapons. According to one congressional report, China is investing heavily in research on directed energy weapons. The report does stipulate, however, that the application favors anti-satellite operations rather than air-to-air applications.[89] Russia also continues to pursue its own directed energy weapon for air defense missions, but little detail is available on the specific intent of the program.[90] Little open source information points toward Russia or China being near the application of lasers to fighter-sized aircraft in the near term, which gives the US the perceived advantage in laser application for the foreseeable future.

If this assessment is accurate, the use of laser weapons could constitute a major advantage in fighter lethality over that of the adversary. Laser weapons with shots traveling at the speed of light over distances equal to or greater than current air-to-air kinetic missile technology, would equate to an order of magnitude increase in capability over enemy fighters. Practically speaking, due to the laser's range capability alone, F-X4 would not need to get nearly as close to take an in-escapable shot at the adversary, increasing its lethality due to its high number of available shots and its survivability due to the increased stand-off range.[91] On the other hand, the same principle would be true for F-X3. Given the same weapons, its stand-off capability also increases. However, what F-X3 gains in weapon capacity and range due to its size, it loses in survivability due to the previously discussed limitations in close range maneuvering and acceleration.

One peering in from an outside perspective could ask what would happen if the enemy acquired and tracked a very low observable aircraft, as Russia and China claim to be able to do now. In the introduction, this project discussed several ways that the US' adversaries are seeking to counter stealth technology, including VHF radar enhancements and passive IR technology.[92] To combat this idea, any aircraft employing laser weapons would now also possess the ability to "jam" or blind enemy radars and passive IR cueing systems using its lasers. This capability requires sufficient range and the ability to find and fix the position of the sensor in question. That being said, the ability to track and engage VLO platforms means, at a minimum, that enemy fighters, SAMs, and other defenses would be able to more aggressively target US aircraft.[93] Unlike F-X1 or F-X3, F-X4 would have the distinct ability to either maneuver against an aircraft that got through to a visual or close range engagement, or to turn and escape the area, thus avoiding being trapped in a no-escape weapon engagement zone.

An alternative perspective on F-X4's application might consider the report recently release by the USAF's Air Superiority 2030 ECCT, which implies that the USAF is moving away from "do it all" systems like those currently designed to penetrate (via stealth), self-escort, drop bombs, gather data and facilitate C2 operations, similar to the F-35 concept. The implied question then is what differentiates F-X4 from an incremental increase in F-35 technology? The answer is rooted in the same ECCT report, where it discusses gaining air superiority using a family of capabilities to execute the "Target" and "Engage" portions of the kill chain.[94] As previously discussed in the scenario narrative, enemy tracking and awareness of US aircraft presence is accepted as fact.[95] With this in mind, F-X4, and to varying degrees, each of the other scenarios in this project, relies on support from other air, cyber and space assets to blind, degrade or otherwise impede enemy tracking and engagement mechanisms. This integrated approach to executing the kill chain, as described in the 2030 flight plan, allows F-X4 to remain specialized without taking on additional roles in the operation. F-X4 should not, then, be modified to take on other responsibilities, and thus technologies that drive the production costs up, ultimately diminishing the true utility of the aircraft in its designed role. As a second order effect, adding redundant capabilities available through other means would also detract from the value and utility of technologies in other domains that can be parlayed across the spectrum of operations. By keeping F-X4 as an air superiority fighter that is able to penetrate and defeat enemy IADS and fighters through a combination of signature management and lethal weapons, it becomes a more affordable option, thus enabling the larger family of capabilities to develop in pursuit of the most efficient, cost effective way to gain and maintain air superiority.

SCENARIO EVALUATION

To evaluate the four scenarios a weighted, risk-reward comparison succinctly illustrates the advantages and disadvantages of each respective platform relative to the others. As discussed in the framework, the three most important key factors of influence (in order of precedence) include: 1) Lethality 2) Survivability 3) Projection (range). These factors can be applied from multiple different perspectives, therefore the specific application of the terms to this project requires further definition.

For the purposes of this research, lethality considers the number of targets each airframe would be able to target, given its payload limitations and the number of targets each platform can reach within its fuel limitations. Payload limitations include both the number of missiles or shots available to the aircraft, as well as the number of different types of targets the aircraft can strike (e.g. air targets, ground targets, soft targets, buried targets, hardened targets and so forth.) As the most important of the three factors in this comparison, airframes score a "+3," "0" or "-3."

Closely following lethality in importance, survivability first considers the platform's ability to maneuver undetected by enemy radar or other detection systems. RF (stealth) and IR (heat dissipation and engine cooling technology) signature management techniques constitute the basis for discussion on detection and tracking. However, as stated in the scenario assumptions, adversary counter stealth technology will likely advance to the point where low observable aircraft can be tracked by enemy systems.[96] The platform's ability to escape from the adversary's weapon engagement zone considers the speed and acceleration available to avoid an engagement if detected and tracked, or the thrust and maneuverability needed to defend itself, maneuver to a weapon engagement zone, and achieve a kill if necessary in close quarter combat.

Acknowledging the potential need for employment from greater ranges than current basing options allow, the third factor is range capability, which equates to the platform's projection capability. Projection considers fuel capacity as the primary determinant. Additionally, design factors such as the possibility for engine efficiency developments or subsonic limitations, both of which increase range, as well as the possibility of increased or decreased land basing options all factor in to the evaluation.

For the evaluation scale, one of three different scores was awarded in each of the above categories. As mentioned, scores were designated on the basis of relative performance to each of the other aircraft. Scores of +X, 0 and -X correlate to a comparison where a score of "+X" equates to the relative reward of the aircraft's capabilities out weighing its risk of mission failure when compared to the other aircraft. Likewise a score of "-X" equates to the opposite circumstance. A score of zero equates to an evaluation where no significant advantage or disadvantage is assessed over the other aircraft.

Scenario #1 – Tortoise or the Hare?

For lethality, F-X1 scores a “0” due to its use of conventional weapons. When compared to the smaller, faster aircraft its payload is significantly larger, but it cannot compare to the potential for an unlimited magazine of the directed energy variants. It does have a capability to carry bombs to attack surface and subsurface, hardened facilities, but this capability is a trade-off to its capacity for air-to-air weapons.

For survivability, F-X1 scores a “-2” due to its dependence on IR and RF signature management techniques for survivability. In the event that it is detected and tracked by enemy counter-stealth technology, it has no ability to escape or to turn and fight in a visual engagement, should enemy fighters or SAMs find a way through its sensors and defenses.

For projection, F-X1 scores a “1” for its high fuel capacity and resulting ability to operate from locations far outside the enemy’s reach (barring ICBM engagements), and its ability to reach targets at strategic distances inside nations such as China and Russia.

Scenario #2 - Jack Be Nimble…

For lethality, F-X2 scores a “-3” due also to its use of conventional weapons, and its smaller payload capacity. Relative to F-X1, (and either of the directed energy options), it has fewer available shots with which to engage enemy targets (both air-to-surface and air-to-air). This does not affect the spectrum of targets it can engage, but it does reduce the number it can engage. It gains the ability to maneuver in close or visual range with another aircraft, which increases its lethality, but with limited reward since close or visual range fights are considered contingency scenarios. These considerations effectively cancel each other out, resulting in zero net change for lethality when compared to F-X1.

For Survivability, F-X2 scores a “0” for its increased ability to survive against an aircraft in close or visual ranges through speed or maneuver. As described in the scenario analysis, the increased probability of a visual engagement over historical numbers necessitates the ability to accelerate and avoid an enemy weapons engagement zone, or to turn an out maneuver an enemy fighter in a visual engagement. It is only given a neutral score however, because it does not enjoy the survivability benefits from DE weapons available to its counterpart, F-X4. These characteristics ensure survivability in a major operation

For Projection, F-X2 scores a “0” due to its smaller size and subsequent reduced fuel capacity. The application of high efficiency motors such as GE’s ACE engine provide a marked increase (assessed at 25 percent) in range capability over typical fighter ranges.[97] However, when compared to that of designs like F-X1 and F-X3, it still lacks the ability to reach strategic ranges deep within nations such as China and Russia.

Scenario #3 - Forward the Light Brigade!

For Lethality, F-X3 scores a “3” due to its use of directed energy weapons. When compared to F-X1 and F-X2, its shot potential is infinite, limited only by its time available on station and the power source utilized for the laser. For air-to-surface targets, F-X3 is assessed to lose the ability to target buried or hardened targets, but the ability to target so many other air and surface targets in pursuit of air superiority far outweighs the risk that loss poses to gaining air superiority.[98]

For Survivability, F-X3 scores a “0” due to its inability to maneuver in close or visual ranges. Relative to F-X1, it gains some ground due to the defensive application of directed energy technologies, but it still is ultimately unable to offset the survivability losses in speed and maneuverability with this capability where survivability is concerned. The increased probability of close and visual engagements in a high volume aerial conflict, like those anticipated in a China or Russia counter A2/AD scenario, makes survivability an imperative to success in achieving air superiority.

For Projection, F-X3 scores a “1” due to its overall size and inherent fuel capacity. Its ability to reach strategic ranges inside a nation like China or Russia increases the number of targets within its reach. Its fuel capacity, like F-X1, also gives it the ability to operate from locations outside the reach of enemy, barring engagement by ICBMs.

<u>Scenario #4 – The Future is Now</u>

For Lethality, F-X4 scores a “3” due to its use of directed energy weapons. Much like F-X3, the number of targets it can engage is limited only by its time on station and the power source for the laser itself. While it will have a shorter loiter time due to its decreased fuel capacity, its targeting capacity still far outweighs the risk its shorter station time poses to success in air superiority operations. Additionally, though it loses the ability to target as many hardened or buried targets due to its reduced capacity for bunker penetrating weapons, much like F-X2, the infinite number of laser shots far outweighs this loss as well. Adding the capability to strike these targets with platforms like LRS-B further diminishes the risk posed by F-X4’s inability to do so.

For Survivability, F-X4 scores a “2,” both due to its ability to avoid enemy weapons engagement zones and to maneuver into its own employment zone should the need arise. Defensive lasers also enhance its survivability in the previously discussed environment where the probability of close or visual engagements increases.[99]

For Projection, F-X4 scores a “0” for the same considerations as F-X2. The primary difference between the two aircraft are the weapons employed. The only difference this could pose in projection is the weight of the weapons themselves, which could have a minor effect on range and fuel efficiency, but it would not result in any overall effect on the platform’s projection capability.

CONCLUSION

When comparing the four scenarios and the associated platforms, it is evident that the most lethal and survivable platform is F-X4, the fast, agile platform which carries DE type weapons. The comparison shows that DE weapons enhance both lethality and survivability over the strict use of kinetic weapons. Maneuverability is not given significant credit towards lethality itself because the majority of engagements will likely be decided beyond visual range. Showing that both types of airframes benefit from the advantages of DE weapons, F-X3 and F-X4 are assessed to be similarly lethal. Survivability however, proved to be the decisive factor in this assessment. F-X1 was the lease survivable due to its lack of either DE weapons, speed to escape or maneuverability to turn and fight if required. F-X2 and 3 scored equally, but for different reasons (one lacked DE weapons and one lacked speed/maneuverability). F-X4 proved to be the most survivable, benefitting from the defensive capabilities of DE weapons, and the ability to escape or maneuver if required.

	F-X_1	F-X_2	F-X_3	F-X_4
Lethality	0	0	3	3
Survivability	-2	0	0	2
Projection	1	0	1	0
	-1	0	4	5

Figure 9. Platform Comparison

Aircraft with larger airframes, (thus higher fuel capacity) scored the best in projection. Efficient engines have the potential to allow fighter sized aircraft to reach strategic ranges someday, but until bomber type fuel capacity is no longer required, the larger airframe aircraft will bring far greater power projection capability to the USAF.

An added note from the scenarios is the illustration that if adversary counter stealth acquisition and tracking technology continue to advance and achieve the ability to cue weapons against stealth aircraft, that future operations could become dependent on third party technology (like stand-off jamming, SAT based jamming and force protection effects, offensive cyber effects, etc.) to remain survivable against advanced surface to air threats. The USAF's guidance on developing a family of capabilities in the air, space, and cyber domains identifies this requirement, and sets out the road map for this idea's requisite development areas. If this guidance truly leads to complimentary, integrated assets that produce combined effects, the USAF has the opportunity to build a lethal, survivable, cost-efficient fighting force that will enable US influence for years to come.

RECOMMENDATIONS

Directed energy development, signature management in the IR and RF spectrum, counter-stealth technology, and kinetic weapons development are all factors that promise to significantly affect future fighter design. The assumptions that underscore the foregoing discussion, as outlined in the scenario assumptions section, offer the primary source for discussion and counter points to this analysis. Additionally, this scenario requires continued increased attention and investment in future capabilities by Congress and DoD leadership.

The USAF should continue to pursue and increase emphasis in the following areas in pursuit of the most lethal, survivable and projectable platform available.

- Increase funding and investment in research toward Mega Watt class directed energy weapons technology, sized appropriately for application to fighter sized aircraft.

- Airframe design to allow both close quarter maneuverability and RF stealth characteristics
- Engine efficiency beyond the ACE motor as produced by GE, and which produces thrust sufficient for supersonic flight in a fighter sized aircraft
- Heat signature reduction technology
    - Both in engine heat management from DE weapons energy production and in skin friction due to airspeed

OPTIONS FOR FURTHER RESEARCH

Figure 10. Fighter application of HEL (Reprinted from Defense News)

This project certainly opens the opportunity for questions and challenges to the assumptions underlying its evaluation and conclusions. Elements like the scoring system, application of technologies, and optimistic views of developmental capabilities are all examples of things that may not reflect other's assessments or fully grasp the technology that is available or its capabilities and limitations. As new technologies continue to mature and the true scope of possibility is realized in their application, further research is warranted on ways to best apply them to the concepts outlined in the Air Superiority 2030 Flight Plan. In the end, lethality, survivability and the ability to project power are imperative to gaining and maintaining air superiority. Underscored by enthusiastic support from congress and sufficient funding to achieve requisite game-changing capabilities, the application of directed energy weapons, supersonic capable motors and the ability to outmaneuver enemy threats constitute the necessary lethality and survivability to meet the USAF’s needs. Coupled with the ability to operate from necessary ranges, as enabled by the family of capabilities currently under development, the Air Force will remain unstoppable in future air superiority operations.

---

[1]Darrell Whitcomb, “The Night They Saved Vega 31,” *Air Force magazine*, Dec 2006, 70-74, http://www.airforcemag.com/MagazineArchive/Pages/2006/December%202006/1206vega.aspx.

[2] Ibid.

[3] Ellis Neal, “Serb discusses 1999 downing of stealth,” *USA Today*, 26 Oct 2005, http://usatoday30.usatoday.com/news/world/2005-10-26-serb-stealth_x.htm.

[4] Dr. Carlo Kopp, “Russian VHF counter stealth radars proliferate,” Maritime Power Australia, Dec 2008, www.ausairpower.net/SP/DT-Rus-VHF-Radar-2008.pdf.

[5] Dr. Carlo Kopp, Almaz-Antey 40R6 / S-400 Triumf Self Propelled Air Defense System / SA-21,” Air Power Australia, Apr 2012, http://www.ausairpower.net/APA-S-400-Triumf.html.

[6] Ibid.

[7] Guy Plopsky & Fabrizio Bozzato, “The F-35 vs. The VHF Threat” *The Diplomat,* 21 Aug 2014, http://thediplomat.com/2014/08/the-f-35-vs-the-vhf-threat/.

[8] Tom Vanden Brook, “Threat from Russian and Chinese warplanes mounts,” *USA Today*, 22 May 2016, http://www.usatoday.com/story/news/politics/2016/05/22/threat-russian-and-chinese-warplanes-mounts/84673228/.

[9] U.S.-China Economic and Security Review Commission, *2015 Report to Congress*, 114th Cong., 1st sess., Nov 2015, pp16, http://www.uscc.gov/annual_reports.

[10] Bill Sweetman, “Gripen Sensors Claim Counter-Stealth Performance,” *Aviation Week & Space Technology*, 17 Mar 2014, http://aviationweek.com/awin/gripen-sensors-claim-counter-stealth-performance.

[11] Sweetman, “Gripen Sensors.” also
Richard D Fisher Jr, “Beijing Tech Show Highlights Advances in Chinese Fighter Sensors,” *IHS Jane's Defense Weekly*, *20* July 2015, http://www.janes.com/article/53064/beijing-tech-show-highlights-advances-in-chinese-fighter-sensors.

[12] Dr. Carlo Kopp, “Sukhoi Flankers, The Shifting Balance of Regional Air Power,” Air Power Australia, 27 Jan 2014, http://www.ausairpower.net/APA-Flanker.html; Fisher, “Beijing Tech Show.”

[13] Hon. Charles Hagel, Secretary of Defense to Deputy Secretary of Defense, et al, memorandum, subject: The Defense Innovation Initiative, 15 Nov 2014, http://www.defense.gov/Portals/1/Documents/pubs/OSD013411-14.pdf

[14] US Fed News Service, Including US State News, “Air Force Launches Air Superiority Enterprise Capability Collaboration Team,” 21 May 2015, http://www.af.mil/News /ArticleDisplay/tabid/223/Article/589175/air-force-launches-air-superiority-enterprise-capability-collaboration-team.aspx.

[15] USAF Enterprise Capability Collaboration Team, “Air Superiority 2030 Flight Plan,” May 2016. http://www.af.mil/Portals/1/documents/airpower/Air%20Superiority%202030% 20Flight%20Plan.pdf.

[16] Yasmin Tadjdeh, “Military Eyes sixth-generation Fighter,” *National Defense*, March 2016, http://www.nationaldefensemagazine.org/archive/2016/March/Pages/MilitaryEyesSixthGenerationFighter.aspx //.

[17] ECCT, “Air Superiority Flight Plan,” pp6.

[18] ECCT, “Air Superiority Flight Plan,” pp4.

[19] Tadjdeh, “Military Eyes Sixth-Gen.” also, “Next Generation Tactical Aircraft (Next Gen TACAIR) Material Technology Concepts Search,” Federal Business Opportunities, 3 November 2010.
https://www.fbo.gov/index?s=opportunity&mode=form&id=782e30c9c983f85e7952c2adc426b189&tab=core&_cview=1 (accessed 9 December 2013).

[20] Dr. Jason Ellis, “Directed Energy Weapons: Promise and Prospects,” (Washington, DC: Center for a New American Security, Apr 2015), pp 4.

[21] Ellis, “Directed Energy,” pp 4.

[22] Ibid, pp 6.

[23] ECCT, “Air Superiority Flight Plan,” pp 7.

[24] Kadir YILDIZ, Murat BİCİL, Sadık AKKAYA, Yavuz İSTEK, “Concepts for Air Supremacy & Essential Capabilities for Modern Air Superiority Assets,” *Conference Proceeding, Scientific Conference AFASES;* (May 2012), EBSCO Host, (90477130).
Scientific Research and Education in the Air Force (AFASES) in Brasov, Romania, 2012).

[25] Yildiz, “Concepts for Air Supremacy.”

[26] Maj. Brandon R. Abel, “Air Superiority And The Anti-Access/Area-Denial Environment in The Asia Pacific In 2044,” (master’s thesis, Air University, April 2014), 24. also
Dr. John Stillion, “Trends in Air to Air Combat,” (Washington, DC: Center for Strategic and Budgetary Assessments, 2015, 58. http://csbaonline.org/publications/2015/04/trends-in-air-to-air-combat-implications-for-future-air-superiority/

[27] Maj. Abel, “Air Superiority,” 24.

[28] Dr. Stillion, “Trends,” 58-59.

[29] Kopp, Carlo, “Russian VHF counter stealth radars proliferate,” *Maritime Power Australia*, Dec 2008 http://gallery.military.ir/albums/userpics/DT-Rus-VHF-Radar-2008.pdf ; also Department of Defense, *“F-35 Selected Acquisition Report (SAR)”* 2015, 67
http://www.dod.mil/pubs/foi/Reading_Room/Selected_Acquisition_Reports/15-F-0540_F-35_SAR_Dec_2014.PDF
– Unit flyaway cost is +/- $100M; Franz-Stefan Gady “India Cleared Purchase of Russian S-400 Missile Defense System” The Diplomat, December 21, 2015 – India will buy 5 regimental units for $4.5B, but it’s a one-time cost, with further costs being measured in the hundreds of thousands for the missiles themselves. Neither considers the development cost or overhead supporting costs, which still likely favor the SAM system in terms of cost efficiency. Therefore the cost of a stealth tracking SAM system will be far cheaper than an Air Force full of F-35s/F-22s.

30 Col. Mike Pietrucha, "Stuck on Denial" War on the Rocks, 24 Mar 2016. http://warontherocks.com/2016/03/stuck-on-denial-part-i-the-u-s-air-force-and-stealth/

31 Yadiz, "Concepts for Air Supremacy."

32 Ibid.

33 Federal Aviation Administration, "Pilot's Handbook of Aeronautical Knowledge," 2008, ch 4, pp 34-46. https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/pilot_handbook/media/PHAK%20-%20Chapter%2004.pdf

34 Col. Mike Pietrucha, "Stuck on Denial" War on the Rocks, 24 Mar 2016. http://warontherocks.com/2016/03/stuck-on-denial-part-i-the-u-s-air-force-and-stealth/

35 Dr. Kopp, "S-400 Triumf."

36 Adam Keck, "US Navy's 6th Generation Fighter Jets Will Be Slow and Unstealthy," *National Interest*, 5 Feb 2015, http://nationalinterest.org/blog/the-buzz/us-navys-6th-generation-fighter-jets-will-be-slow-unstealthy-12193. See quote by Chief of Naval Operations, Adm. Jonathan Greenert,

37 Dr. Stillion, "Trends," pp 35.

38 DoD, "F-35 SAR," pp 67. Unit flyaway cost is +/- $100M; Franz-Stefan Gady "India Cleared Purchase of Russian S-400 Missile Defense System" The Diplomat, December 21, 2015 – India will buy 5 regimental units for $4.5B, but it's a onetime cost, with further costs being measured in the hundreds of thousands for the missiles themselves. Neither considers the development cost or overhead supporting costs, which still likely favor the SAM system in terms of cost efficiency. Therefore the cost of a stealth tracking SAM system will be far cheaper than an Air Force full of F-35s/F-22s. ; Also consider the cost of a jamming pod when compared to a fighter aircraft,

39 Sweetman, Bill, "New Radars, IRST Strengthen Stealth-Detection Claims" *Aviation Week & Space Technology*, 16 Mar 2015, http://aviationweek.com/technology/new-radars-irst-strengthen-stealth-detection-claims.

40 Thom Patterson, "Laser Armed Fighter Jets by 2020, U.S. Air Force Says" CNN, 17 Dec 2015, http://www.cnn.com/2015/12/17/politics/us-air-force-laser-fighter-jet-weapons-research/.

41 Tadjdeh, "Military Eyes Sixth-Gen." also
Guy Norris and Jen DiMascio, "Northrop's Game Plan," Aviation Week & Space Technology, 21 Dec 2015, pp 24-25, http://archive.aviationweek.com/issue/20151221#!&pid=1.

42 The "packaged solution" refers to the F-35 and its application as a single fighter to meet all requirements for all services. By leveraging multi-domain capabilities, (Space based sensors, weapons and other developmental technology, Cyber techniques and offensive capabilities, maritime/sub-surface assets, etc.) the DoD will be able to force multiply a far more specialized aircraft than the F-35. The same theory would apply to the temptation to equip the LRS-B (or any other aircraft) with too many additional capabilities, thus reducing its utility as a strategic asset. While it is not this projects intent to advocate for a "single-mission" aircraft, the F-22 represents a balance between specialization and multi-role capabilities.

43 Dr. Stillion, "Trends," pp 36-38.

44 "Adaptive Cycle Engine Datasheet," General Electric, 2015, http://www.geaviation.com/engines/docs/military/datasheet-adaptive-cycle.pdf.

45 Sweetman, "Gripen Sensors."

46 Dr. Stillion, "Trends," pp 47.

47 Patterson, "Laser-Armed Fighter Jets."

[48] Dr. Stillion, "Trends," pp 48.
[49] Wendell Minnick, "China Puts Guam Within Missile Range," *Defense News*, 12 May 2016, http://www.defensenews.com/story/defense/international/asia-pacific/2016/05/12/ china-guam-us-missile-range/84279494/
[50] http://amti.csis.org/island-tracker/
[51] Vice Admiral Thomas Rowden, Rear Admiral Peter Gumataotao, and Rear Admiral Peter Fanta, U.S. Navy, "Distributed Lethality," *Proceedings Magazine*, 343, Vol. 141/1/1, January 2015, http://www.usni.org/magazines/proceedings/2015-01/distributed-lethality.
[52] "Adaptive Cycle Engine Datasheet," GE
[53] Curtis E. LeMay Center for Doctrine Development and Education, *Volume 3, Annex 3-01, Counterair Operations,"* 1 Feb 2016, pp 3, https://doctrine.af.mil/ DTM/ dtmcounterairops.htm
[54] Diana Scearce, Katherine Fulton, *What If? The Art of Scenario Thinking for Nonprofits*, (Global Business Network: 2004), 10-14.
[55] Office of the Historian, US Department of State, "Southeast Asia Treaty Organization (SEATO), 1954," accessed 25 June 2016, https://history.state.gov/milestones/1953-1960/seato
[56] SAT based laser jamming technique adapted from SAT based missile defense concepts "Space Based Lasers" Federation of American Scientists, 17 Feb 2015, http://fas.org/spp/ starwars/program/sbl.htm
[57] Eric Heginbotham, et al., "The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power 1996-2017," RAND Report RR-392-AF (Washington, DC: RAND, 2015), 71-93, http://www.rand.org/pubs/research_reports/RR392.html.
[58] Dr. Stillion, "Trends," pp 25-28.;
The reduced number of visual merges is also attributed to increased friendly situational awareness (for instance the SA provided by AWACS to fighters and other air assets)and beyond visual range engagement capabilities (via the AMRAAM and relatively new 4th generation fighter capabilities)
[59] Ibid.
[60] Dr. Stillion, "Trends," np; also Maj. Abel, "Air Superiority," np
[61] Dr. Stillion, "Trends," ch 4.
[62] Robert Hewson, "Briefing: Teeth of the Dragon," *Janes Defense Weekly*, (Jan 17, 2011) https://janes-ihs-com.aufric.idm.oclc.org/Janes/Display/1185840#blockImage
[63] "AIM-120," Globalsecurity.org, July 11, 2011, http://www.globalsecurity.org/ military/systems/munitions/aim-120.htm; also
"PL-21," Globalsecurity.org, 7 Nov 2011, http://www.globalsecurity.org/ military/world/china/pl-21.htm.
[64] "AIM-120 AMRAAM anti-air missile," Military Periscope, Sept 2015, https://www-militaryperiscope-com.aufric.idm.oclc.org/weapons/missrock/antiair/w0003591.html.
[65] Dr. Stillion, "Trends," ch 4.
[66] Dr. Kopp, "Russian VHF Counter Stealth."
[67] Dr. Stillion, "Trends," ch 4. also
Dr. Kopp, "Russian VHF Counter Stealth."
[68] The assumption here is that this concept is used to execute air superiority operations throughout the theater.
Dr. Stillion, "Air-to-Air Trends," ch 4.
While this report talks about the number of aircraft required to execute in these scenarios, current US plans do not include the use of large numbers of UCAVs to support a concept like what Dr.

Stillion describes. Operational plans and basing would have to be modified to accommodate the increased number of UCAV aircraft if Mr. Stillion's idea was implemented fully.

[69] Guy Plopsky & Fabrizio Bozzato, "The F-35 vs. The VHF Threat" *The Diplomat,* 21 Aug 2014, http://thediplomat.com/2014/08/the-f-35-vs-the-vhf-threat/.

[70] Dr. Stillion, "Trends," 58-59.

[71] "USAF Strategic Master Plan," May 2015, pp56, http://www.af.mil/Portals/1 /documents/Force%20Management/Strategic_Master_Plan.pdf.

[72] Close range can be defined in several different ways. Within visual range is generally considered to be within 3-4NM, depending on the size of the fighter. The AMRAAM is considered a medium range missile by title, and its maximum range (unclassified) is 30NM. For the purposes of this research, close range can be considered to be anywhere between the ranges of the AMRAAM and a within visual range engagement, although a specific range is not necessary to define.

[73] Guy Norris, and Jen DiMascio, "Northrop's Game Plan," Aviation Week & Space Technology (December 21, 2015-January 3, 2016,) pp 24-25.

[74] "SU-35 Flanker: Multi-purpose fighter," Military Periscope, 1 Apr 2009, https://www-militaryperiscope-com.aufric.idm.oclc.org/weapons/aircraft/fighter/w0005306.html.

[75] "Adaptive Cycle Engine Datasheet," GE.

[76] Bill Sweetman, "Lockheed Reveals New Air Launched Missile Concepts," *Aviationweek*, Sept 2013, http://aviationweek.com/awin/lockheed-reveals-new-air-launched-missile-concepts.

[77] Dr. Stillion, "Trends," pp 32-38.

[78] ECCT, "Air Superiority Flight Plan," pp 4.

[79] Sec. Hagel memorandum

[80] Dr. Phillip Nielson, "The Effects of Directed Energy Weapons" National Defense University, Center for Technology and National Security Policy, 1994, 101-169, in Dr. Ellis, "Directed Energy Weapons."

[81] Dr. Carlo Kopp, "High Energy Laser Directed Energy Weapons" Air Power Australia, May 2008, http://www.ausairpower.net/APA-DEW-HEL-Analysis.html#mozTocId345541.

[82] Robin Hughes, "Raytheon Selected to Deliver Next-Generation Tactical Air-to-Air Missile Solutions," 21 Jan 2016, http://www.janes.com/article/57493/raytheon-selected-to-deliver-next-generation-tactical-air-to-air-missile-solutions.

[83] Seligman, Laura, "The Air Force of the Future: Lasers on Fighter Jets and Planes that Think," Defense News, 20 Feb 2016, http://www.defensenews.com/story/defense/air-space/2016/02/20/air-force-future-lasers-fighter-jets-planes-think/80515698/.

[84] Dave Majumdar, "America's F-22 Raptor Stealth Fighter Is a Killer (But it Can Be Defeated)," *National Interest,* 15 Oct 2015, http://nationalinterest.org/blog/the-buzz/americas-f-22-raptor-stealth-fighter-killer-it-can-be-14088?page=2.

[85] Ellis, "Directed Energy," pp 31.

[86] Dr. Stillion, "Trends," pp 25-29.

Heginbotham, "The U.S.-China Military Scorecard," 92.

Dr. Stillion cites the decrease in visual engagements in Operation Desert Storm. Mr. Heginbotham discusses the number of wings required to achieve 50% attrition, illustrating that the air threat is far more significant in terms of capability and volume…thus increasing the potential of a visual merge.

[87] "Adaptive Cycle Engine Datasheet," GE.

[88] Ellis, "Directed Energy," pp 4.

[89] US-China Economic and Security Review Report: 2015, p289.
[90] Dr. Kopp, "High Energy Lasers."
[91] Dr. Nielson, "The Effects of Directed Energy"
Ellis, "Directed Energy," pp 36-37.
This statement assumes that directed energy weapons can be employment at ranges consistent with those depicted for chemical lasers in figure 2. Although according to CNAS's directed energy weapons report there are no currently active chemical weapons development programs, DARPA continues to seek 100+ KW laser power through its Excalibur solid state laser program, which the CNAS report states has the potential to reach MW outputs.
[92] Russia IRST, VHF tracking stealth articles. Dr. Kopp, "Russian VHF Counter Stealth."
[93] Bill Sweetman, "New Radars, IRST Strengthen Stealth-Detection Claims," *Aviation Week & Space Technology*, 16 Mar 2015, http://aviationweek.com/technology/new-radars-irst-strengthen-stealth-detection-claims
[94] Air Superiority 2030 flight plan, pp 7.
[95] Greenert comments on anything hot/moving will be tracked
[96] Zachary Keck, "US Navy's 6th Generation Fighter Jets Will Be Slow and Unstealthy," *National Interest*, 21 Apr 2016. http://nationalinterest.org/blog/the-buzz/us-navys-6th-generation-fighter-jets-will-be-slow-unstealthy-12193
[97] "Adaptive Cycle Engine Datasheet," GE.
[98] Ellis, "Directed Energy," pp 36-37.
[99] Seligman, "The Air Force of the Future."

BIBLIOGRAPHY

Abel, Maj. Brandon R. *Air Superiority and the Anti-Access/Area-Denial Environment in the Asia Pacific in 2044.* Maxwell AFB, AL: Air University. April 2014

Air Superiority 2030 Flight Plan. USAF Enterprise Capability Collaboration Team Report. Washington, DC. May 2016. http://www.af.mil/Portals/1/documents/airpower/ Air%20Superiority%202030% 20Flight%20Plan.pdf.

Curtis E. LeMay Center for Doctrine Development and Education. "Annex 3-01, Counterair Operations," 1 Feb 2016. https://doctrine.af.mil/ DTM/ dtmcounterairops.htm

Ellis Dr. Jason. *Directed Energy Weapons: Promise and Prospects*, Washington, DC: Center for a New American Security. Apr 2015.

Hagel, Hon. Charles, Secretary of Defense. To Deputy Secretary of Defense, et al, Memorandum. Subject: The Defense Innovation Initiative. 15 Nov 2014. http://www.defense.gov/Portals/1 /Documents/pubs/OSD013411-14.pdf

Heginbotham, Eric, et al. *The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power 1996-2017.* RAND Report RR-392-AF. Washington, DC: RAND, 2015. http://www.rand.org/pubs/research_reports/RR392.html.

Nielson, Dr. Phillip. *The Effects of Directed Energy Weapons.* Fort Lesley J. McNair, Washington, DC: National Defense University, Center for Technology and National Security Policy, 1994. In Ellis, Dr. Jason. *Directed Energy Weapons: Promise and Prospects*, Washington, DC: Center for a New American Security. Apr 2015.

Rowden, Vice Admiral Thomas, Rear Admiral Peter Gumataotao, and Rear Admiral Peter Fanta, U.S. Navy. "Distributed Lethality." *Proceedings Magazine* Vol. 141/1/1 (January 2015): 343. http://www.usni.org/magazines/proceedings/2015-01/distributed-lethality.

Stillion, Dr. John. *Trends in Air to Air Combat*. Washington, DC: Center for Strategic and Budgetary Assessments. 2015. http://csbaonline.org/publications/2015/04/trends-in-air-to-air-combat-implications-for-future-air-superiority/

U.S.-China Economic and Security Review Commission. *2015 Report to Congress*, 114th Cong., 1st sess. Nov 2015. http://www.uscc.gov/annual_reports.sdf

USAF Strategic Master Plan. May 2015. http://www.af.mil/Portals/1 /documents/ Force%20Management/Strategic_Master_Plan.pdf.

YILDIZ, Kadir, Murat BİCİL, Sadık AKKAYA, Yavuz İSTEK, "Concepts for Air Supremacy & Essential Capabilities for Modern Air Superiority Assets." *Conference Proceeding, Scientific Conference AFASES*. May 2012. EBSCO Host, (90477130).